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PHYSICAL PROPERTY MEASUREMENTS OF DOPED CESIUM IODIDE CRYSTALS

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August 30, 1974

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16. Abstract

This report presents mechanical and thermal property values of crystalline cesium iodide doped with sodium and thallium that can be used for the design and fabrication of High Energy Astronomical Observatory (HEAO) experiments. Although nominal values of the physical properties of undoped cesium iodide are available in the open literature, systematic testing of doped cesium iodide had not been done previously. Sodium doped cesium iodide has been thoroughly investigated as a scintillator only recently, and flight experiments have used relatively small crystals compared to HEAO requirements. Cesium iodide has a high density (and thus better stopping power) and less sensitivity to moisture compared to sodium iodide; other scintillating materials that could be used to detect and measure high energy radiation have additional disadvantages. The widespread use of cesium iodide in HEAO experiments and our lack of knowledge of physical properties justified a testing program to investigate the characteristics and variations of this material.

Fewer than six companies in the world manufacture the high quality crystalline cesium iodide required for high energy cosmic radiation experiments. The two major suppliers of cesium iodide in this country, Harshaw Chemical Company of Cleveland, Ohio, and Isotopes, Inc., of Westwood, New Jersey, were selected to provide us with representative samples for our testing. Young's modulus, bulk modulus, shear modulus, and Poisson's ratio were obtained from ultrasonic measurements. Young's modulus and the samples' elastic and plastic behavior were also measured under tension and compression. Thermal expansion and thermal conductivity were the temperature dependent measurements that were made. Although average values can be selected for each of these measurements, the variation in these values with dopant material and location within a larger crystal was considered equally important.

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TABLE OF CONTENTS

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LIST OF ILLUSTRATIONS

LIST OF TABLES

PHYSICAL PROPERTY MEASUREMENTS OF DOPED CESIUM IODIDE CRYSTALS

INTRODUCTION

The plan to test cesium iodide doped with sodium, CsI(Na), and cesium iodide doped with thallium, CsI(Tl), was initiated in June 1971. Harshaw Chemical Company prepared a list of mechanical, thermal, and optical properties (Table 1) which they considered were not well known. Discussions were held with the principal investigators of the High Energy Astronomical Observatory (HEAO), and it was agreed that the mechanical properties were insufficiently known to design any large crystal experiment, such as the 91.44 cm (36 in.) diameter crystal of EGRET and the thin slabs of similar dimensions planned for HECRE. The thermal expansion coefficient was known to be large, but the measurements would need to be repeated for both dopants. The optical testing suggested by Harshaw would not be done because any significant optical efficiency test would have to consider the source of scintillation, crystal configuration, and crystal packaging. These measurements were considered the responsibility of each principal investigator.

The criteria for specifying crystal samples for testing considered the nature of the manufactured crystal ingot, required processing for the HEAO experiments, and testing capabilities of available equipment. The Bridgeman crystal growth method is used by both Harshaw and Isotopes to grow crystals up to 91.44 cm (36 in.) in diameter. This method produces crystals known to vary in dopant concentration from the upper part of the crystal to the bottom because of the varying distribution of the dopant in the melt during solidification. Samples were requested to be cut from the upper and lower portions of the crystal consistent with the high and low dopant requirements specified by the principal investigator. The shallow angle of the crystal growth crucible tends to produce multiple crystals rather than one large single crystal, so variations in physical properties are also expected from the center to the outside of the crystal. Therefore, crystal samples were requested to be cut parallel to the major axis of the crystal as well as parallel to the other axes. Cylindrical symmetry was expected, therefore precise specification of the orthogonal axes was not required.

TESTING PROGRAM AND RESULTS

All measurements on the crystal samples were conducted in rooms with the temperature and humidity controlled. The relative humidity in all testing areas was below 50 percent for most of the testing. The samples from Harshaw were delivered with desiccant containers and double plastic bags to ensure dry storage conditions. The samples from Isotopes were not packed with desiccant, but surface degradation was not noticed with any of the samples before testing was completed.

Both Harshaw and Isotopes provided samples according to Table 2 with each sample labeled according to the scheme: CYT signifies a sample cut from the Central part of the Thallium doped crystal along the Y-axis. Each company cut the samples from ingots approximately 45.72 cm (18 in.) in diameter and 35.56 cm (14 in.) deep. Large rectangular pieces were also ordered, 25.4 cm (10 in.) square and 1.27 cm (0.5 in.) thick, and subsequently sent to Goddard Space Flight Center for analysis of optical efficiency and packaging techniques. Harshaw developed a restructured form of cesium iodide during 1971 named Polyscin II, and specimens of sodium doped Polyscin II were received for testing. Since Polyscin II is produced by a different technique, the labeling TY denotes a sample from the Trailing part of the ingot, cut along the Y-axis.

Samples were delegated to two nondestructive testing techniques to acquaint personnel with the nature of the material before destructive measurements under tension and compression were begun. Some representative samples of each size were not tested so that unplanned tests could still be conducted at a later date.

The floating beam resonant technique and the ultrasonic velocity measurement technique were used to determine the elastic properties of cesium iodide. The resonant or dynamic method of measuring the elastic modulus suspends a uniform rod at its nodal points on adjustable cross wires. Mechanical vibration is transmitted to the rod from a piezoelectric transducer by means of a fine coupling wire. A similar system receives the mechanical vibration from the specimen. This received signal increases sharply in amplitude as an oscillator is adjusted to match the resonant frequency of the specimen. The transverse mode of vibration is more precise and was selected for making these measurements. The 0.95 cm (0.375 in.) diameter round samples were used for these tests, and the formulas used to derive the pertinent moduli are listed in Table 3. The Young's modulus values obtained by this technique are tabulated as Table 4.

Longitudinal and shear wave ultrasonic velocity measurements were made on the 2.54 cm (1 in.) diameter round samples. This was accomplished by adjusting a calibrated acoustic path length through distilled water until sound propagation times through the sample and the water were equal. Knowledge of the path lengths involved and the velocity of sound in water allows the velocities to be determined. This technique was used to further substantiate the Young's modulus values of Table 4 and to give accurate determinations of the bulk modulus, shear modulus and Poisson ratio as shown in Table 5.

Physical testing of the samples by applying loads in tension and compression was also begun. An Instron Universal testing machine was used to apply the load at a constant rate of displacement. Measurements in tension were made by clamping the 10.16 cm (4 in.) long samples securely over a 2.54-cm (1-in.) length at each end. Strain measur- .ents were made with bonded resistance strain gauges. The displacement of the clamps [0.005 cm/min (0.002 in./min) for all measurements] and the load applied were measured simultaneously to give the required stress/strain curves.

Establishment of a reliable testing procedure for tension and compression measurements was complicated by the ductile nature of cesium iodide. Strain gauges and a slow displacement under load were required to give the elastic portion of the stress/strain curve. The early measurements under tension using linear voltage differential transources did not give reliable Young's modulus values but the proportional limit and ultimate strength were obtained for a representative group of samples, as shown in Table 6.

The design engineers of the HEAO experiments using cesium iodide requested increased emphasis on testing under compressive loads since these measurements would influence their designs. The compression tests were done with 1.27 cm (0.5 in.) round and square samples cut 5.08 cm (2 in.) long. Table 7 summarizes the data and gives the distance each 5.08-cm (2-in.) sample was compressed before the test was stopped. The Young's modulus, Y, and the proportional limit, P, vary considerably and representative curves have been retraced from the original data as Figures 1 through 6 to help interpret the results in Table 7.

Thermal conductivity and thermal expansion measurements were requested because of the sensitivity of cesium iodide to temperature excursions. Thermal conductivity measurements at three different temperatures showed little variation for either CsI(Na) or CsI(Tl). Only two samples of each species were tested because of the noncriticality of this parameter. The thermal expansion coefficient of both materials was determined with a quartz tube

dilatometer. Measurements of the thermal expansion coefficient made at 11°C (20°F) intervals from -18°C to 149°C (0°F to 300°F) were linear within ±5 percent. The apparatus measured the change in length over the temperature interval under consideration with an accuracy of ±2 percent. The thermal properties of doped cesium iodide are summarized in Table 8.

The creep of different crystal samples under both tensile and compressive loads is now being measured under iosthermal conditions. Previous measurements of creep have required sensitivities in the range of 25.4^{-5} cm (10^{-5} in.) which is the distance the 5.08-cm (2-in.) samples expand over a temperature interval of 0.1°C (0.18°F). Sensitive and long time interval measurements of creep have begun and will be reported when available.

DISCUSSION OF RESULTS

The three techniques used to determine Young's modulus of doped cesium iodide (floating beam resonance, ultrasonic velocity and compressive yield) give an average value of 13.9×10^{10} dynes/cm^2 (2×10^6 psi), which is almost three times higher than the previously published value of 5.3×10^{10} dynes/cm^2 (7.7×10^5 psi) for undoped cesium iodide. Additional samples of undoped cesium iodide were measured (Table 4) but the error cannot be attributed to the presence of the dopant. Sufficient duplication of the measurements and techniques occurred to substantiate the average Young's modulus given in this report.

The bulk modulus averaged 11.73×10^{10} dynes/cm^2 (1.7×10^6 psi), which is close to the published value of 12.42×10^{10} dynes/cm^2 (1.8×10^6 psi). The shear modulus averaged 6.9×10^{10} dynes/cm^2 (1.0×10^6 psi), which is close to the published value of 6.21×10^{10} dynes/cm^2 (0.90×10^6 psi). Poisson's ratio has not been previously reported, and its average value was determined to be 0.26.

The compression test measurements are widely divergent. Their variation can be attributed to the crystalline character of the cesium iodide and the presence of grain boundaries, slip planes, and faults inherent in any grown crystal of large size. Although the variation in property values is not unexpected, the low proportional limit of some of the samples is cause for concern. Portions of any grown crystal that yield readily under compressive loads will have to be planned in any design, since it would be difficult to analyze the large crystal configurations on HEAO for the location and extent of slip planes, crystal boundaries, etc. The variations are not attributable to either the sodium or thallium dopant or any specific region of the crystal.

The thermal expansion coefficient is large compared to most metals and must be an important consideration in the engineering design. The thallium doped crystal had a consistent 10 percent higher thermal expansion coefficient than the sodium doped cesium iodide.

Several discussions have been held with technical representatives of Harshaw and the HEAO principal investigators to devise methods of working with this unusual engineering material. The results of the testing, summarized in the tables of this report, have been available to the concerned principal investigators and this information must be coupled with the scientific data to be obtained from the cesium iodide assemblies.

CONCLUSIONS

The basic mechanical and thermal properties of CsI(Na) and CsI(Tl) have been assembled in this report. Although the average values are provided for experiment design, the wide variation in some of these values because of the crystalline and polycrystalline nature of the material are of comparable interest.

Creep data will be available as an addendum to this report. Long term creep is especially needed because of the time involved between fabrication and launch into space. These measurements will be reported on a periodic basis.

Since each cesium iodide configuration on HEAO is different, this report has primarily reported the testing results. For example, the ductility of cesium iodide is both an advantage and disadvantage depending upon the application. Each experiment must carefully consider the crystalline nature of cesium iodide.

Additional testing may be required because of experiment requirements not previously identified. Some samples are available that can be used depending upon the nature of the test.

TABLE 1. BASIC PROPERTIES FOR INVESTIGATION

1. <u>Technical Scope of Inquiry</u>

1.1 General — The inquiry should concern CsI, (suitable for scintillation detectors) as produced by Harshaw Chemical Company. The purification, growth, and other processes involved in making CsI scintillators are proprietary and may not be divulged. Each sample provided for test purposes will be evaluated for its scintillation efficiency. No sample will be used which falls below some agreed upon performance. The recommended tests will be performed on a sufficiently large number of samples.

1.2 Mechanical Properties — The following properties shall be measured for single and polycrystalline CsI.

1.2.1 Young's modulus
Bulk modulus
Shear modulus
Poisson ratio
Tensile strength
Fatigue
Plastic flow
Hardness

The sample shape and orientation of single crystals shall be chosen for each test to provide meaningful values of the intrinsic properties.

1.2.2 Effects of crystal boundaries on measurements of intrinsic properties; e.g., slip shear stress, tensile strength.

1.3 Thermal Properties — The following properties shall be measured for single and polycrystalline samples.

1.3.1 Thermal expansion coefficients
Thermal conductivity

1.4 Optical Properties — The principal optical property deemed relevant to this program is the transmission of the CsI to its scintillation radiation. Since in general the transmission is very high (i.e., absorption is ~ 0.001 cm^{-1}), the measurement is difficult with normal instruments and samples of reasonable size. It is proposed that transmission measuring techniques be devised for use with samples relevant to the various experimental configurations.

TABLE 2. CESIUM IODIDE SPECIMEN REQUIREMENTS

Specimen Location in Ingot	Upper Portion of Ingot			Central Portion of Ingot			Lower Portion of Ingot		
Specimen Orientation[a]	X-Cut	Y-Cut	Z-Cut	X-Cut	Y-Cut	Z-Cut	X-Cut	Y-Cut	Z-Cut
Specimen Dimensions	Number of Specimens Required								
0.95 cm (0.375 in.) Diameter by 10.16 cm (4.0 in.) Long		2 S[b] 2 T	2 S 2 T	2 S 2 T	2 S 2 T	2 S 2 T		2 S 2 T	2 S 2 T
1.27 cm (0.5 in.) Diameter by 10.16 cm (4.0 in.) Long		2 S 2 T	2 S 2 T	2 S 2 T	2 S 2 T	2 S 2 T		2 S 2 T	2 S 2 T
2.54 cm (1.0 in.) Diameter by 10.16 cm (4.0 in.) Long		2 S 2 T	2 S 2 T	2 S 2 T	2 S 2 T	2 S 2 T		2 S 2 T	2 S 2 T
0.47 cm (0.1875 in.) by 1.27 cm (0.5 in.) by 10.16 cm (4.0 in.)		2 S 2 T	2 S 2 T	2 S 2 T	2 S 2 T	2 S 2 T		2 S 2 T	2 S 2 T
1.27 cm (0.5 in.) by 1.27 cm (0.5 in.) by 10.16 cm (4.0 in.)		2 S 2 T	2 S 2 T	2 S 2 T	2 S 2 T	2 S 2 T		2 S 2 T	2 S 2 T
25.4 cm (10.0 in.) Diameter by 1.27 cm (0.5 in.) Thick				1 S 1 T					

a. Specimen orientation is referenced to the schematic sketch of a CsI ingot and the illustrated X-, Y-, and Z- axes. Specimen location; i.e., upper, central and lower, refers to the upper, central and lower portions of the cylindrical section of the ingot.

b. S denotes specimens doped with sodium; T denotes specimens doped with thallium.

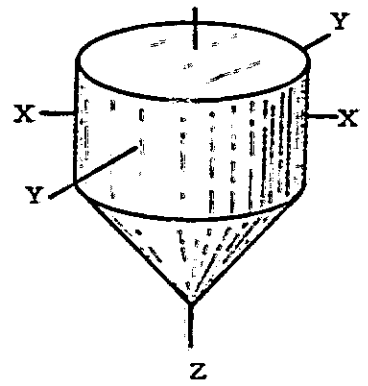

TABLE 3. APPLICABLE FORMULAS[a]

$$\mu = V_T^2 \rho$$

$$\sigma = \frac{1 - 2\left(\frac{V_T}{V_L}\right)^2}{2 - 2\left(\frac{V_T}{V_L}\right)^2}$$

$$Y = 2\mu \; (\sigma + 1)$$

$$K = \frac{Y}{3\,(1 - 2\sigma)}$$

$$Y = 1.2615 \left(\frac{\rho L^4}{d^2}\right) F_T^2$$

where

μ = shear modulus, dynes/cm^2

ρ = density, grams/cm^3

V_T = transverse velocity, cm/sec

σ = Poisson's ratio

V_L = longitudinal velocity, cm/sec

Y = Young's modulus, dynes/cm^2

L = length, cm

d = diameter, cm

F_T = transverse resonant frequency

K = bulk modulus, dynes/cm^2

a. From Non-Destructive Testing Handbook, Robert C. McMaster, Editor, Ronald Press Company, N. Y., 1963, page 43.10.

TABLE 4. YOUNG'S MODULUS VALUES OBTAINED BY MECHANICAL MEASUREMENTS

Reported in the Literature CsI: 5.3×10^{10} dynes/cm^2 = 7.7×10^6 psi
From Transverse Vibration, $\times 10^{10}$ dynes/cm^2

			Average	
Thallium Doped	Harshaw	Isotopes	$\times 10^{10}$ dynes/cm^2	$\times 10^6$ psi
UZ	16.7	15.5	16.4	2.4
	17.5	16.0		
UY	16.1	1[illegible].2	16.6	2.4
	15.8	17.5		
CZ	16.2	16.7	16.4	2.4
	16.3	16.5		
CX	17.6		17.6	2.6
	1.7			
CY	15.8	16.4	16.2	2.3
	15.5	17.0		
LY	16.3	16.5	16.5	2.4
	16.2	16.9		
LZ	16.5	15.8	16.1	2.3
		15.9		
Sodium Doped				
UZ	16.2		16.6	2.4
	17.0			
UY	17.6		17.6	2.6
	17.7			
CZ	16.3		16.2	2.3
	16.0			
CX	15.9		15.8	2.3
	15.7			
CY	17.5		17.1	2.5
	16.7			
LY	17.4		17.6	2.6
	17.9			
LZ	16.6		16.8	2.4
	17.1			
Undoped				
	15.6			
	15.4			
	16.1			
	15.7			

TABLE 5. MECHANICAL PROPERTIES FROM ULTRASONIC VELOCITY MEASUREMENTS

Sample	Bulk Modulus		Shear Modulus		Poisson's Ratio
	$\times 10^{10}$ dynes/cm^2	$\times 10^6$ psi	$\times 10^{10}$ dynes/cm^2	$\times 10^6$ psi	
UYT	12.07	1.75	6.969	1.01	0.26
UZT	11.04	1.60	7.03	1.02	0.23
UYS	11.04	1.60	7.935	1.15	0.21
UZS	10.97	1.59	6.555	0.95	0.21
CYT	13.31	1.93	6.969	1.01	0.28
CXT	13.52	1.96	6.279	0.91	0.30
CZT	11.59	1.68	6.486	0.94	0.26
CXS	11.45	1.66	7.03	1.02	0.24
CZS	12.0	1.74	6.555	0.95	0.27
LYT	12.42	1.80	6.76	0.98	0.27
LYS	12.83	1.86	6.21	0.90	0.29
LZS	12.97	1.88	6.348	0.92	0.29

TABLE 6. TENSION TESTS

Sample	Manufacturer	Young's Modulus, Y		Proportional Limit, P		Ultimate Strength		Comments[a]
		$\times 10^{10}$ dynes/cm^2	$\times 10^6$ psi	$\times 10^4$ dynes/cm^2	psi	$\times 10^4$ dynes/cm^2	psi	
UYT	Harshaw	21.39	3.1	1849.2	268	3022.2	438	
UYT	Harshaw			1462.8	212	2925	424	$\Delta X = 0.76$ cm (0.30 in.)
UYS	Harshaw			2208	320	5934	860	$\Delta X = 1.40$ cm (0.55 in.)
CXT	Harshaw			1987.2	288	2649.6	384	$\Delta X = 2.29$ cm (0.90 in.)
CZT	Isotopes	15.87	2.3	1759.5	255	4795.5	695	$\Delta X = 1.85$ cm (0.73 in.)
CZT	Isotopes			2070	300	4050.3	587	$\Delta X = 0.74$ cm (0.29 in.)
LYT	Isotopes			2277	330	2863.5	415	$\Delta X = 1.27$ cm (0.50 in.)
LZT	Isotopes			731.4	106	2359.8	342	$\Delta X = 2.48$ cm (0.975 in.)
LZT	Harshaw			2014.8	292	3760.5	545	—
TYZB	Harshaw			2242.5	325	2242.5	325	—

a. Samples 10.16 cm (4.0 in.) long were clamped 2.54 cm (1.0 in.) from each end for thest tests.

TABLE 7. COMPRESSION TESTS

Sample	Manufacturer	Young's Modulus, Y		Proportional Limit, P		Comments
		$\times 10^{10}$ dynes/cm^2	$\times 10^6$ psi	$\times 10^4$ dynes/cm^2	psi	
CZS	Harshaw	11.04	1.6	1055.7	153	Loaded to 1235.1×10^4 dynes/cm^2 (179 psi), then back to 0
		19.32	2.8	1228.2	178	Loaded to 1304.1×10^4 dynes/cm^2 (189 psi), then back to 0
		15.87	2.3	1228.2	178	Loaded to 1304.1×10^4 dynes/cm^2 (189 psi), then back to 0
		14.49	2.1	1228.2	178	Sample buckled at 1794×10^4 dynes/cm^2 (260 psi)
CZS	Harshaw	13.9	2.0	524.4	76	Loaded to 1124.7×10^4 dynes/cm^2 (163 psi), then back to 0
		15.87	2.3	1124.7	163	Loaded to 1193.7×10^4 dynes/cm^2 (173 psi), then back to 0
		15.18	2.2	1159.2	168	Sample buckled at 1476.6×10^4 dynes/cm^2 (214 psi)
CZT	Isotopes	14.49	2.1	1380	200	Loaded to 22080×10^4 dynes/cm^2 (3200 psi)
		6.9	1.0	1380	200	Loaded to 2070×10^4 dynes/cm^2 (300 psi), then back to 0
		12.42	1.8	1600.8	232	Loaded to 1600.8×10^4 dynes/cm^2 (232 psi), then back to 0
		14.49	2.1	1600.8	232	Loaded to 1600.8×10^4 dynes/cm^2 (232 psi), then back to 0

TABLE 7. (Continued)

Sample	Manufacturer	Young's Modulus, Y		Proportional Limit, P		Comments
		$\times 10^{10}$ dynes/cm^2	$\times 10^6$ psi	$\times 10^4$ dynes/cm^2	psi	
CZT	Isotopes	14.49	2.1	1600.8	232	Loaded to 1600.8×10^4 dynes/cm^2 (232 psi), then back to 0
		12.42	1.8	1655	240	Loaded to 1863×10^4 dynes/cm^2 (270 psi), then back to 0
		13.8	2.0	1656	240	Loaded to 1863×10^4 dynes/cm^2 (270 psi), then back to 0
		14.49	2.1	1656	240	Loaded to 1863×10^4 dynes/cm^2 (270 psi), then back to 0
		14.49	2.1	1656	240	Loaded to 1863×10^4 dynes/cm^2 (270 psi), then back to 0
		13.8	2.0	1656	240	Buckled at 6900×10^4 dynes/cm^2 (1000 psi), $\Delta X = 1.52$ cm (0.60 in.)
CZT	Isotopes	11.73	1.7	966	140	$\Delta X = 0.20$ cm (0.08 in.) at 2760×10^4 dynes/cm^2 (400 psi)
CZT	Isotopes			993.6	144	$\Delta X = 0.25$ cm (0.10 in.) at 2760×10^4 dynes/cm^2 (400 psi)
CZT	Harshaw	11.73	1.7	1711.2	248	$\Delta X = 0.76$ cm (0.30 in.) at 7314×10^4 dynes/cm^2 (1060 psi)
LYT	Isotopes	28.98	4.2	1214.4	176	$\Delta X = 0.508$ cm (0.20 in.) at 2704.8×10^4 dynes/cm^2 (392 psi)
LYT	Isotopes	9.66	1.4	579.6	84	$\Delta X = 0.43$ cm (0.17 in.) at 2546.4×10^4 dynes/cm^2 (356 psi)

TABLE 7. (Continued)

Sample	Manufacturer	Young's Modulus, Y		Proportional Limit, P		Comments
		$\times 10^{10}$ dynes/cm^2	$\times 10^6$ psi	$\times 10^4$ dynes/cm^2	psi	
UYT	Harshaw	16.56	2.4	1104	160	$\Delta X = 0.23$ cm (0.09 in.) at 2760×10^4 dynes/cm^2 (400 psi)
UYT	Harshaw			1159.2	168	$\Delta X = 0.36$ cm (0.14 in.) at 2622×10^4 dynes/cm^2 (380 psi)
LYT	Harshaw	9.66	1.4	358.8	52	$\Delta X = 0.4$ cm (0.16 in.) at 2346×10^4 dynes/cm^2 (340 psi)
LYS	Isotopes	11.73	1.7	1242	180	$\Delta X = 0.06$ cm (0.025 in.) at 2760×10^4 dynes/cm^2 (400 psi)
LYS	Isotopes	11.73	1.7	1159.2	168	$\Delta X = 0.04$ cm (0.015 in.) at 2760×10^4 dynes/cm^2 (400 psi)
LZT	Isotopes	9.66	1.4	276	40	$\Delta X = 0.30$ cm (0.12 in.) at 2346×10^4 dynes/cm^2 (340 psi)
LZT	Isotopes	15.87	2.3	979.8	142	$\Delta X = 0.25$ cm (0.10 in.) at 2456.4×10^4 dynes/cm^2 (356 psi)
LZT	Harshaw	24.84	3.6	607.2	88	$\Delta X = 0.43$ cm (0.17 in.) at 2428.8×10^4 dynes/cm^2 (352 psi)
LZT	Harshaw	10.35	1.5	745.2	108	$\Delta X = 0.36$ cm (0.14 in.) at 2042.4×10^4 dynes/cm^2 (296 psi)
LZS	Harshaw	12.42	1.8	2352.9	341	$\Delta X = 0.38$ cm (0.15 in.) at 4830×10^4 dynes/cm^2 (700 psi)
LZS	Harshaw	15.18	2.2	690	100	$\Delta X = 0.20$ cm (0.08 in.) at 2235.6×10^4 dynes/cm^2 (324 psi)

TABLE 7. (Continued)

Sample	Manufacturer	Young's Modulus, Y		Proportional Limit, P		Comments
		$\times 10^{10}$ dynes/cm^2	$\times 10^6$ psi	$\times 10^4$ dynes/cm^2	psi	
TY3A	Harshaw	9.66	1.4	876.3	127	Loaded to 3105×10^4 dynes/cm^2 (450 psi), then back to 0
		15.18	2.2	876.3	127	Loaded to 3105×10^4 dynes/cm^2 (450 psi), then back to 0
		12.42	1.8	1587	230	Loaded to 3105×10^4 dynes/cm^2 (450 psi), then back to 0
		13.11	1.9	1725	250	Loaded to 3105×10^4 dynes/cm^2 (450 psi), then back to 0
		10.35	1.5	1725	250	Buckled at 4795.5×10^4 dynes/cm^2 (695 psi)
TY2A	Harshaw	21.39	3.1	1380	200	$\Delta X = 0.08$ cm (0.03 in.) at 5520×10^4 dynes/cm^2 (800 psi)
		30.36	4.4	1518	220	$\Delta X = 0.18$ cm (0.07 in.) at 5934×10^4 dynes/cm^2 (860 psi)
UYT	Isotopes	23.46	3.4	1159.2	168	Buckled at 2352.9×10^4 dynes/cm^2 (341 psi)
UYT	Isotopes	16.56	2.4	1104	160	$\Delta X = 0.228$ cm (0.09 in.) at 2760×10^4 dynes/cm^2 (400 psi)
UYT	Isotopes			1518	220	$\Delta X = 0.355$ cm (0.14 in.) at 2622×10^4 dynes/cm^2 (380 psi)
UZT	Isotopes	10.35	1.5	552	80	$\Delta X = 0.43$ cm (0.17 in.) at 2428.8×10^4 dynes/cm^2 (352 psi)

TABLE 7. (Concluded)

Sample	Manufacturer	Young's Modulus, Y		Proportional Limit, P		Comments
		$\times 10^{10}$ dynes/cm^2	$\times 10^6$ psi	$\times 10^4$ dynes/cm^2	psi	
UZT	Isotopes	5.5	0.8	276	40	$\Delta X = 0.40$ cm (0.16 in.) at 2649.6×10^4 dynes/cm^2 (384 psi)
UZT	Isotopes	20.01	2.9	828	120	Buckled at 2304.6×10^4 dynes/cm^2 (334 psi)
CXT	Isotopes	16.56	2.4	690	100	$\Delta X = 0.20$ cm (0.08 in.) at 1380×10^4 dynes/cm^2 (200 psi)
CXT	Isotopes	6.9	1.0	1104	160	$\Delta X = 0.28$ cm (0.11 in.) at 2760×10^4 dynes/cm^2 (400 psi)
CXS	Isotopes	28.29	4.1	455.4	66	$\Delta X = 1.32$ cm (0.52 in.) at 1279.5×10^4 dynes/cm^2 (1055 psi)
CYT	Isotopes	9.66	1.4	414	60	$\Delta X = 0.43$ cm (0.17 in.) at 2760×10^4 dynes/cm^2 (400 psi)
CYT	Isotopes	4.14	0.6	552	80	$\Delta X = 0.56$ cm (0.22 in.) at 2760×10^4 dynes/cm^2 (400 psi)
CYS	Isotopes	15.18	2.2	552	80	$\Delta X = 0.33$ cm (0.13 in.) at 4416×10^4 dynes/cm^2 (640 psi)
CYS	Isotopes	30.36	4.4	966	140	$\Delta X = 0.28$ cm (0.11 in.) at 5382×10^4 dynes/cm^2 (780 psi)

TABLE 8. THERMAL PROPERTIES OF DOPED CESIUM IODIDE

Thermal Expansion	
Reported in Literature, CsI	$5 \times 10^{-5}/°C$
Reported in Literature, CsI(Na)	$4.7 \times 10^{-5}/°C$
MSFC Measurements, CsI(Tl)	$5.4 \times 10^{-5}/°C$
MSFC Measurements, CsI(Na)	$4.9 \times 10^{-5}/°C$
Thermal Conductivity at 0°C	
Reported in Literature, CsI	29×10^{-4} cal/sec cm^2 °C
Reported in Literature, CsI(Na)	500×10^{-4}
MSFC, CsI(Tl) and CsI(Na)	37×10^{-4} at 0°C and 50°C
	39×10^{-4} at 100°C

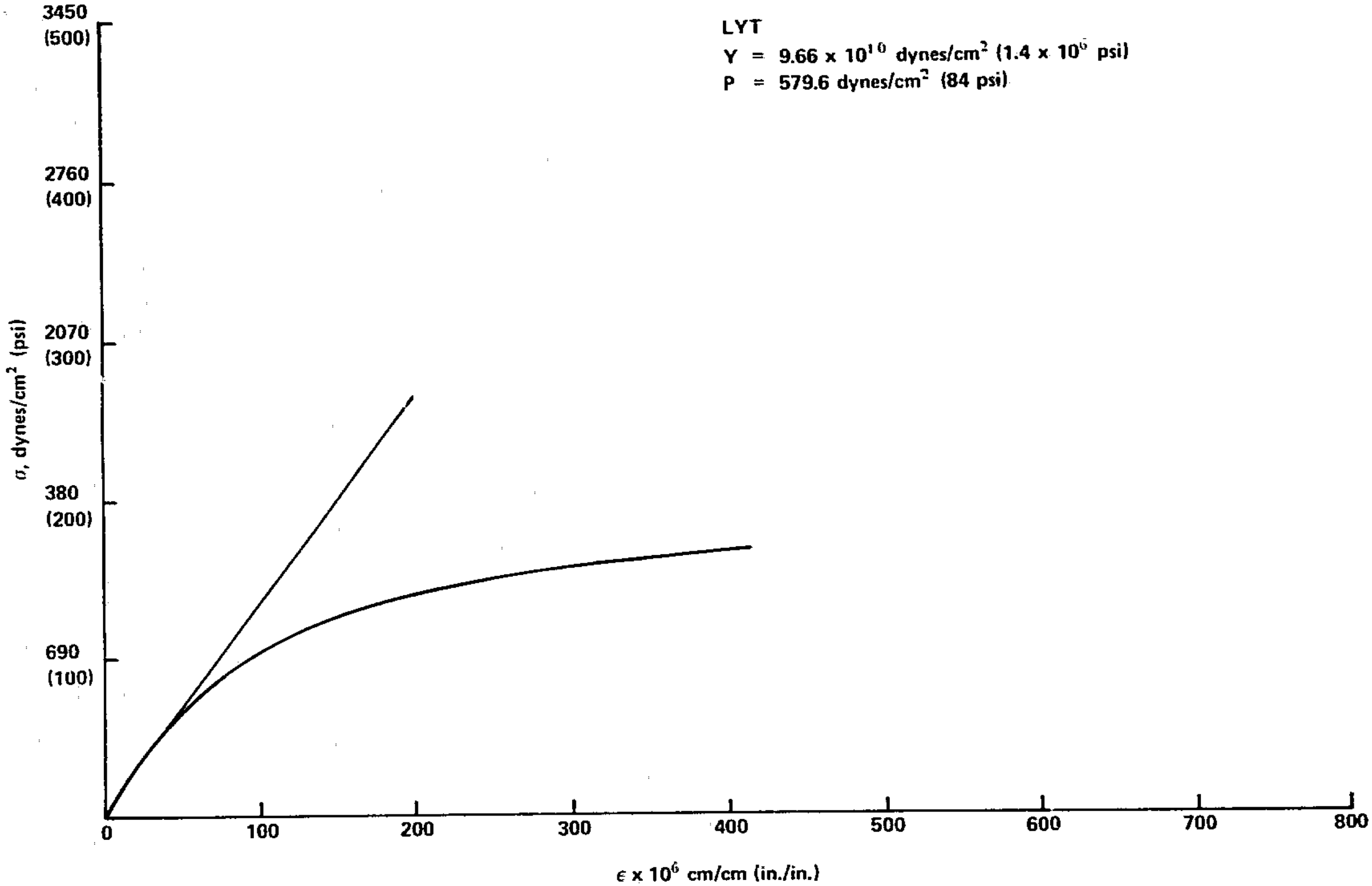

Figure 1. Young's modulus.

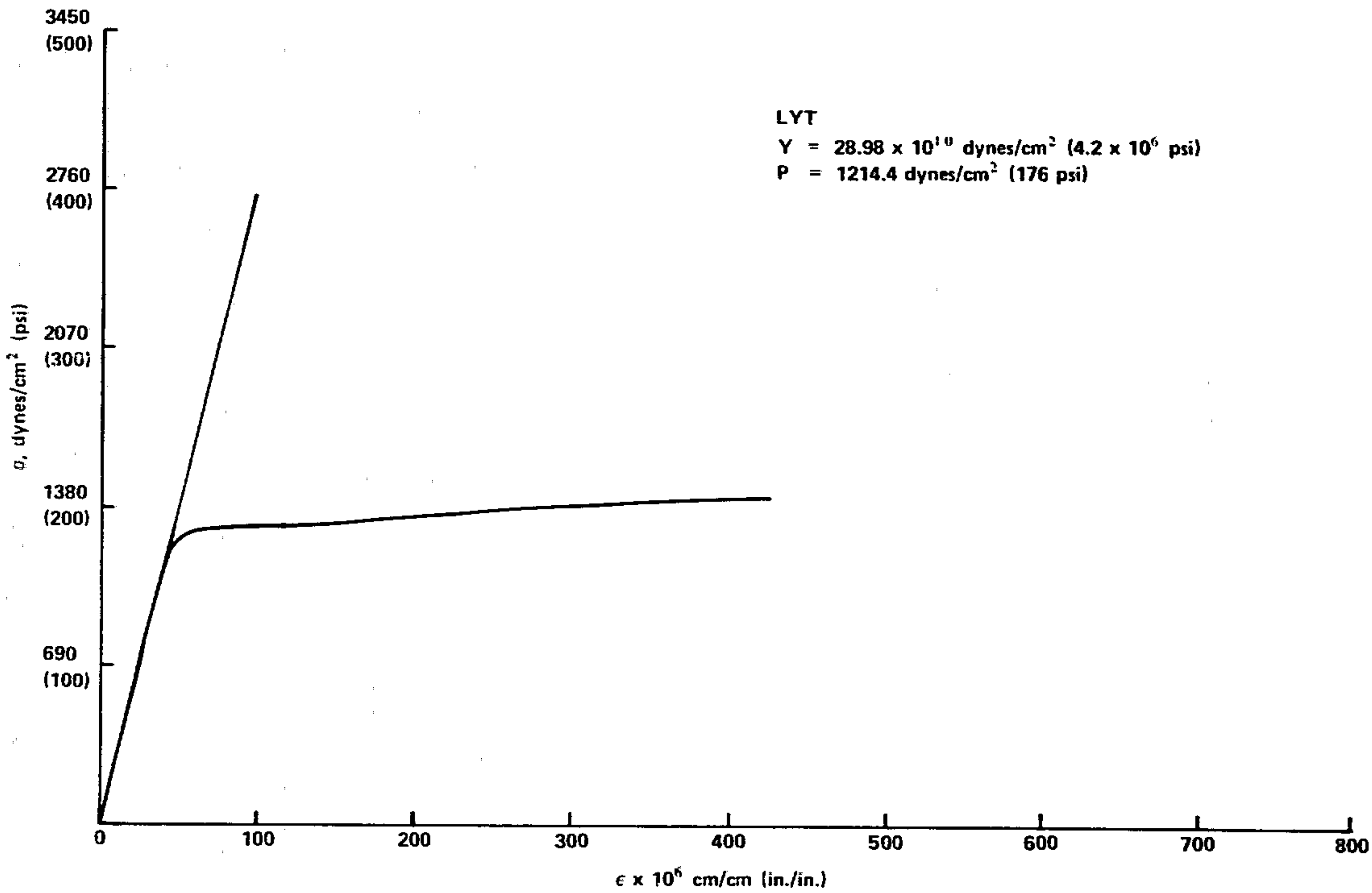

Figure 2. Young's modulus.

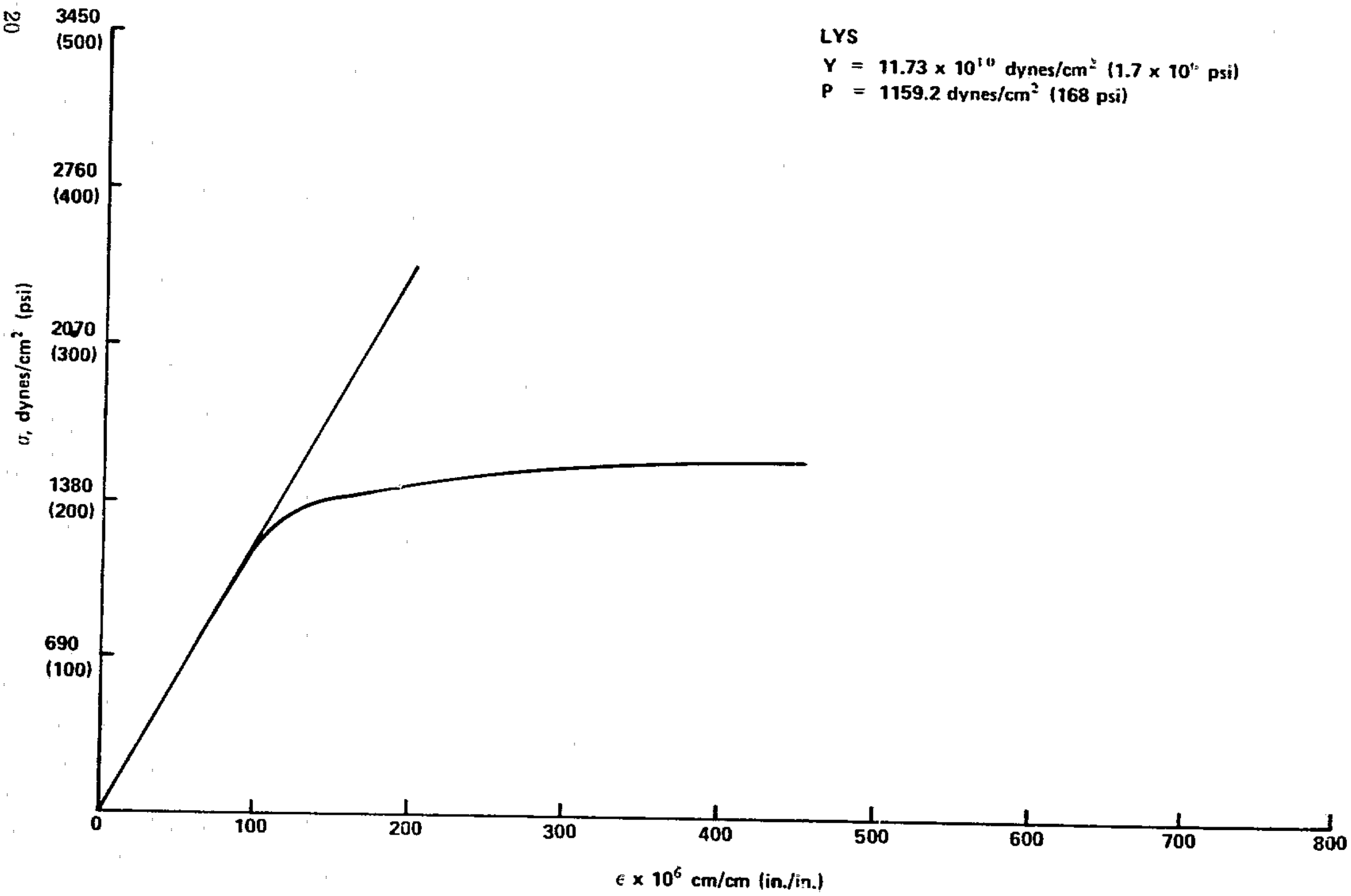

Figure 3. Young's modulus.

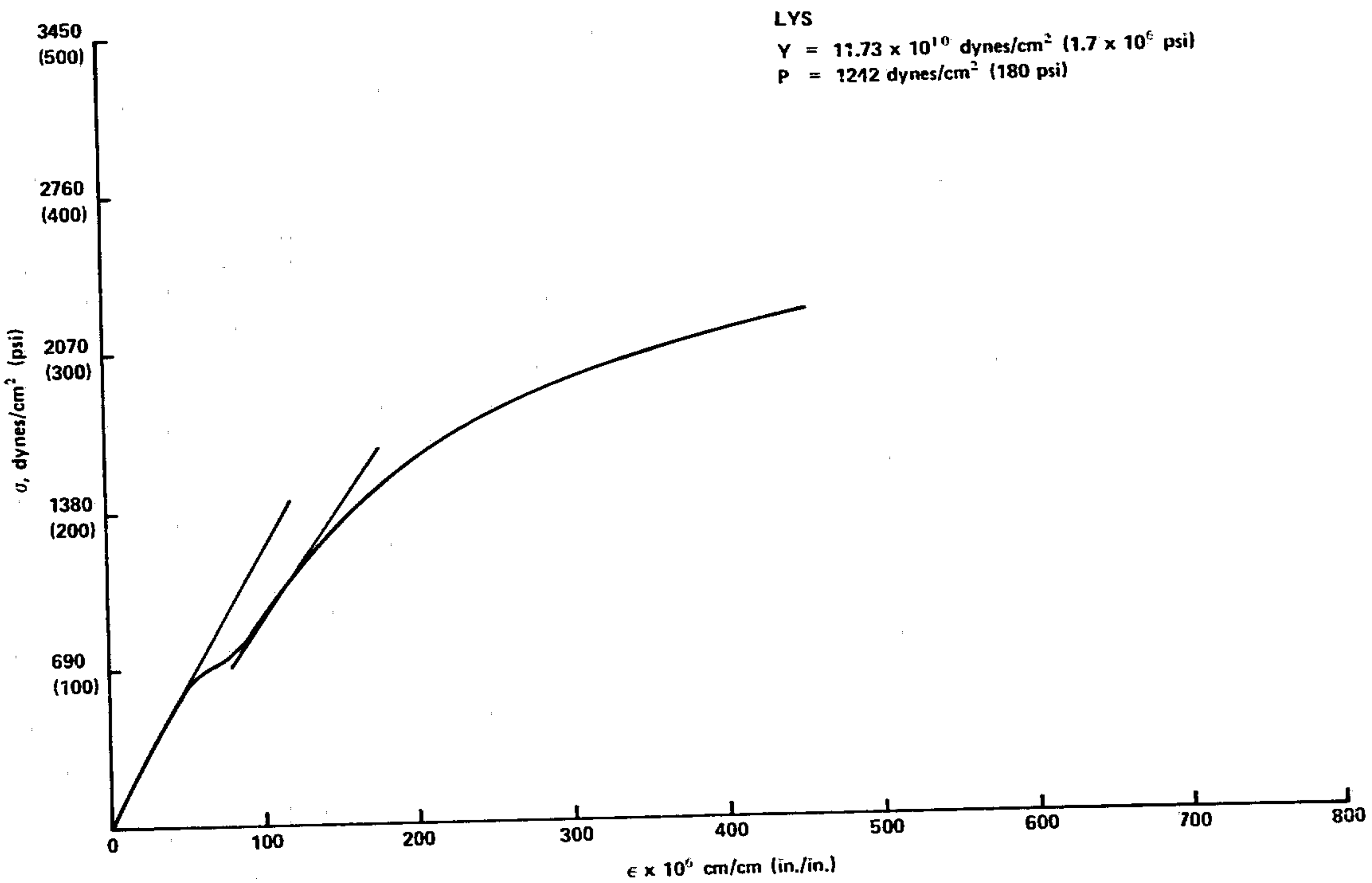

Figure 4. Young's modulus.

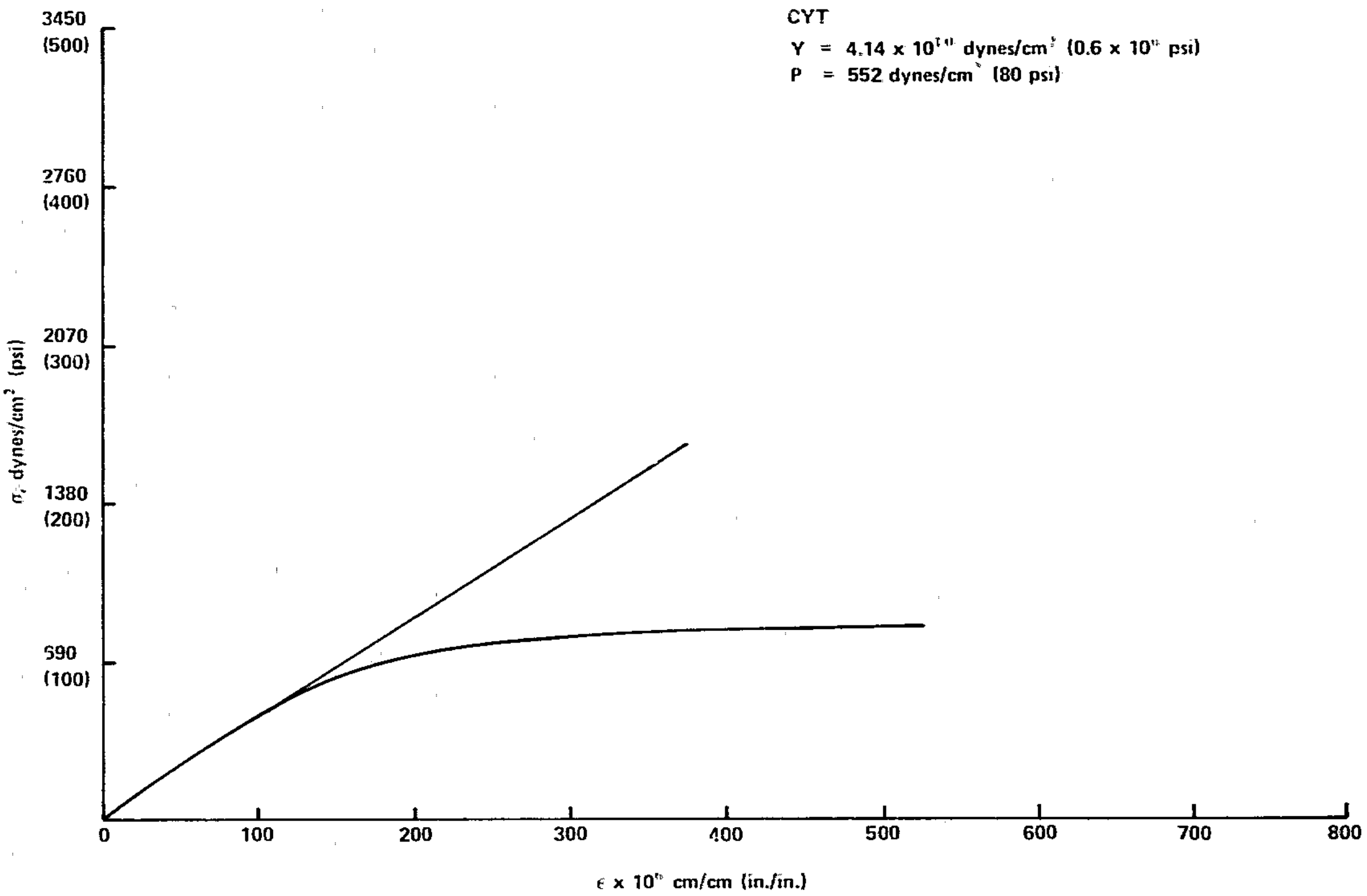

Figure 5. Young's modulus.

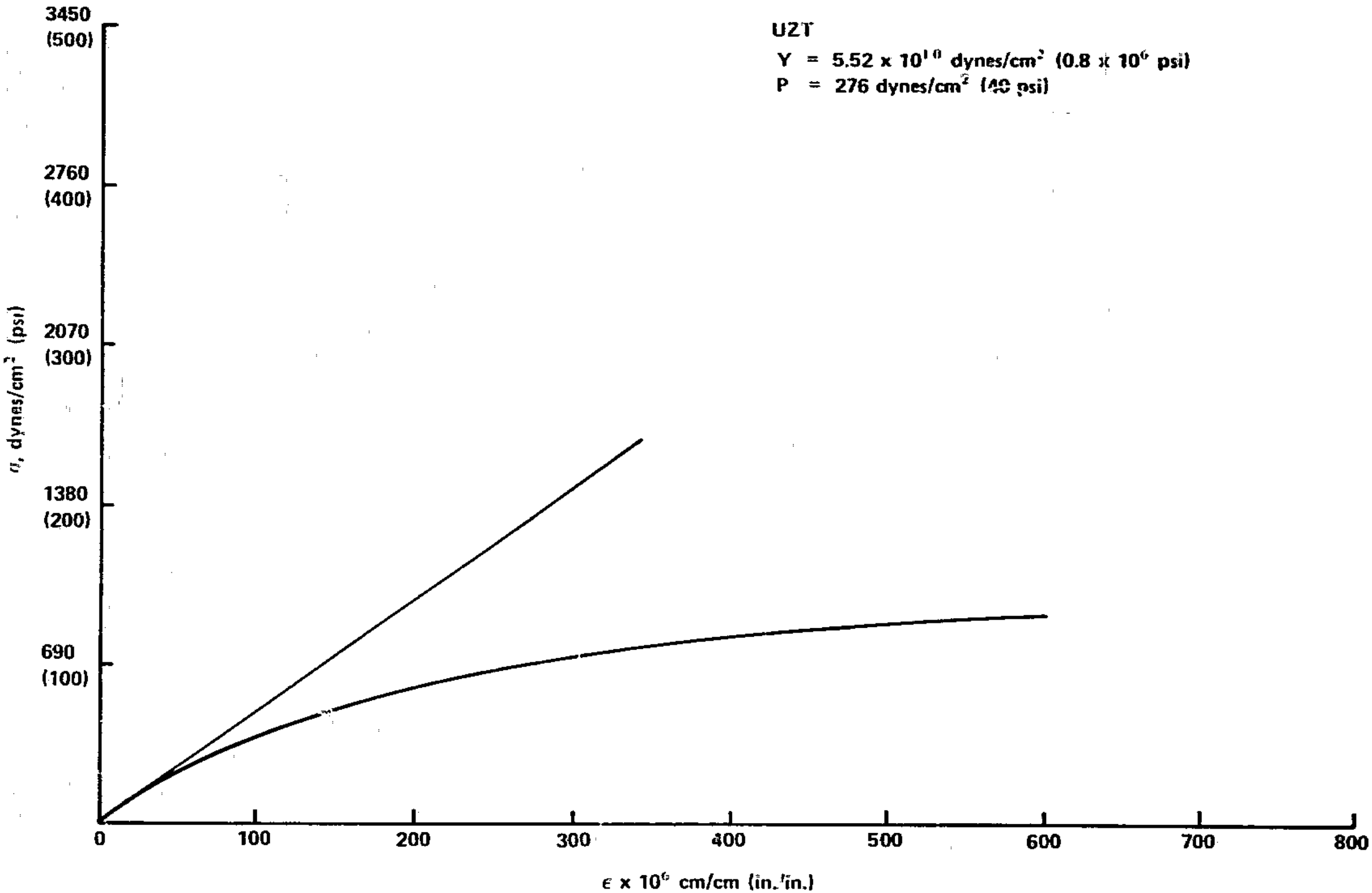

Figure 6. Young's modulus.

APPROVAL

PHYSICAL PROPERTY MEASUREMENTS OF DOPED CESIUM IODIDE CRYSTALS

By R. S. Snyder and W. N. Clotfelter

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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